PARALLEL SPREAD SPECTRUM
COMMUNICATION SYSTEM AND METHOD

5 RELATED APPLICATION

The present invention claims priority to U.S. Provisional Patent Application No. 60/268,942 filed on February 16, 2001, which is incorporated herein in its entirety.

BACKGROUND OF THE INVENTION

10 1. Field of the Invention

The present invention relates to digital communications, and more particularly, to systems and methods for providing spread spectrum related communications.

2. Description of Related Art

Spread spectrum communication techniques are finding broad applications. For example, spread spectrum originated in the military where communications are susceptible to detection/interception and vulnerable to intentionally introduced interference/jamming. However, a host of commercial applications for spread spectrum has evolved, particularly in the area of wireless communications, such as cellular mobile communications.

The basic concept of spread spectrum is contrary to long standing communications practices. Particularly, conventional practices focused on minimizing the frequency bandwidth of an information-bearing signal in order to fit more signals onto a communications link (channel). The goal of spread spectrum, in contrast, is to substantially increase the bandwidth of an information-bearing signal. Indeed, a spread spectrum communications link occupies a bandwidth substantially greater than the minimum requirements for a standard communications link. That is, a spread spectrum signal typically occupies a bandwidth well beyond the bandwidth that is required to transmit digital data according to the Nyquist theorem. As discussed in greater detail below, this bandwidth increase helps mitigate the harmful effects of various forms of interference.

In a spread spectrum system, a transmitter spreads (increases) the bandwidth of an information-bearing signal prior to transmission. A receiver, upon receipt of the signal, despreads (decreases) the bandwidth by substantially the same amount. Ideally, the despreaded received signal is identical to the transmitted signal prior to spreading. However, the communication

channel regularly introduces some form of narrow band (relative to the spread bandwidth) interference.

One general type of spread spectrum system is direct sequence spread spectrum ("DSSS"). With DSSS systems the spreading is achieved by multiplying the digital data with a binary pseudo-noise sequence "PN-sequence" or "PN-code"), which is alternatively known as a pseudo-random sequence or chipping code, whose symbol rate is many times the binary data bit rate. The spreading sequence symbol rate is sometimes called the chip-rate. The chipping code is independent of the data and includes a redundant bit pattern for each bit that is transmitted. The code, in effect, increases the transmitted signal's resistance to interference. If one or more bits in the pattern are damaged during the transmission, the original data can be recovered due to redundancy in the transmission. A pseudo-noise sequence is a sequence of chips valued at -1 or 1 (polar), or 0 and 1 (non-polar), which possess exceptional correlation properties.

Fig. 1 illustrates a conventional direct sequence ("DS") spread spectrum spreading technique. There are several types of well known pseudo-noise sequences which can be used with DSSS systems, for example, M-sequences, Gold codes, and Kasami codes; each type of sequence or code having its own peculiar characteristics. The number of chips within one code is called the period (N) of this code. For instance, if a complete PN-sequence is multiplied with a single data bit (as in **Fig. 1**, with $N=7$), the bandwidth of the signal is multiplied by the factor N, which also is referred to as a processing gain. In other words, the processing gain in spread spectrum communications is directly related to the length of the sequence. Referring to **Fig. 2A**, the effect on the power spectrum is that the power spectral density has the shape of a $sinc^2(x)$ function, if a M-sequence code is used.

The benefits of using spread spectrum techniques can be readily seen through the necessity of interference suppression. There are generally three categories of inferences that a signal can experience: jammed, multiple access, and multipath. Jammed interference occurs when another signal is deliberating (as with a military jammer) or is inadvertently superimposed on the signal. Multiple access interference occurs when the signal shares the same frequency spectrum with other signals. Multipath interference occurs when the signal itself is delayed.

With respect to jammed interference, a hostile party or "jammer" has a difficult time locating a spread spectrum signal. In fact, after spreading, the spread spectrum signal is confused with the noise, see **Fig. 2B**, and a jamming signal is limited to a small part of the

spectrum; after despreading of the signal, the jamming is attenuated to the level of noise, see **Fig. 2C**, and the information can be recovered, see **Fig. 2D**. In commercial applications, the primary advantage of spread spectrum communication is the elimination of concentrated interference from another transmitter.

5   Spread spectrum benefits regarding multiple access interference have great commercial utility. From the perspective of commercial applications, spread spectrum communications allow multiple users to communicate on the same frequency band. When used in this manner, it becomes an alternative to either frequency division multiple access ("FDMA") or time division multiple access ("TDMA") and is typically referred to as either code division

10   multiple access ("CDMA") or spread spectrum multiple access ("SSMA"). When using CDMA, each signal in the set is given its own spreading sequence. FDMA requires that all users occupy disjoint frequency bands but are transmitted simultaneously in time. TDMA requires that all users occupy the same bandwidth by allocating unique time slots to each user within each channel. In contrast, with CDMA the different waveforms are distinguished from one another at

15   the receiver by the specific spreading codes they employ.

            CDMA has been of particular interest for applications in wireless communications. These applications include cellular communications, personal communications services ("PCS"), and wireless local area networks. The reason for this popularity is primarily due to the performance that spread spectrum waveforms display when transmitted over a

20   multipath fading channel. To illustrate this concept, consider DS signaling. As long as the duration of a single chip of the spreading sequence is less than the multipath delay spread, the use of DS waveforms provides a system designer with one of two options. The multipath can be treated as a form of interference, which means the receiver should attempt to attenuate it as much as possible. Indeed, under this condition, all of the multipath returns that arrive at the receiver

25   with a time delay greater than a chip duration from the multipath return to which the receiver is synchronized (usually the first return) will be attenuated because of the processing gain of the system. Alternately, the multipath returns that are separated by more than a chip duration from the main path represent independent "looks" at the received signal and can be used constructively to enhance the overall performance of the receiver. That is, because all of the multipath returns

30   contain information regarding the data that is being sent, information can be extracted by an appropriately designed receiver.

Thus, the benefits of spread spectrum communications are that different spreading codes can be used so that multiple links can operate on the same frequencies simultaneously. Another benefit afforded by this technique is that the processing gain allows spread spectrum communication links to work at much lower signal levels than conventional radio links.

5   Conventional spread spectrum systems, however, have several drawbacks. One problem with conventional wireless systems is that they have considerable RF transmitter power requirements. Particularly in portable hand-held cellular devices, it is believed that these power requirements and the associated strong electromagnetic signals of the device may negatively affect human physiology. Another relevant drawback with conventional systems is the short

10   battery life of portable devices in certain applications. Additionally, conventional spread spectrum systems require a large communication bandwidth and the number of users on each bandwidth is limited by the number of spreading codes.

Another drawback is that spread spectrum is subjected to the NEAR-FAR effect. This problem is caused by the fact that a receiver may receive several signals with unequal

15   powers from multiple transmitters. Generally the transmitted signal power from a non-reference transmitter is suppressed in the receiver by the cross-correlation properties of the reference code. However, if the non-reference transmitter is much closer than the reference transmitter it is probable that the received signal from the non-reference transmitter will constitute substantially more power than the reference transmitter. In this case, the PN correlator in the receiver shall be

20   unable to detect and despread the weak reference transmission.

Another significant drawback is that conventional systems cannot pragmatically and efficiently provide enhanced processing gain. Currently, spread spectrum techniques do not support large PN-sequence lengths that improve processing gain. In addition, conventional systems are unable to utilize optimal processing gain simultaneously with forward error

25   correction.

SUMMARY OF THE INVENTION

The present invention teaches bi-sequential parallel spread spectrum methods and systems. The invention advantageously combines a series of code sequences to produce an

30   enhanced and robust communications technique that can be implemented in a broad variety of applications, including point-to-point or point-to-multipoint wireless communication systems.

In one preferred embodiment of the invention, a wireless communication system includes a transmitter and a receiver station. A bi-sequential parallel spread spectrum method that includes the combination of a primary and a secondary code sequences is utilized. In accordance with the invention, the transmitting station performs the steps of encoding a digital data signal with a primary coding scheme, such as an orthogonal Walsh coding scheme; spreading the encoded signal with a secondary sequence, such as a PN-sequence; modulating the spread encoded signal, using for example, DBPSK modulation; and transmitting the modulated signal. The receiver station, in accordance with this preferred embodiment, performs the steps of despreading the received signal using a stored secondary sequence; demodulating the despreaded signal; and decoding the demodulated signal using the primary coding scheme.

The use of multiple short spreading codes in parallel layers radically enhances processing gain and multiple access attributes.

The invention also provides enhanced processing gain simultaneously with forward error correction.

Another significant advantage of the invention is that the enhanced processing gain allows for a reduction in transmitted power requirements. For example, an 18 dB processing gain theoretically means that only 1/8 of the RF transmitter power requirement is necessary for the communications link. The lower power requirements of the invention may reduce health issues and allow for longer battery use in certain applications.

An additional advantage of the invention is that independent spreading sequences can be utilized in both the In-phase and Quadrature channels thereby, allowing enhanced link security.

A still further advantage of the invention is improved bandwidth efficiency. For example, the invention typically provides more than five (5) times greater bandwidth efficiency than conventional spread spectrum techniques with identical processing gain attributes.

Another advantage of the invention is that forward error correction algorithms can be implemented at the receiver to improve bit-error rate performance.

A further advantage of the invention is the use of a reduced acquisition period due to the use of short PN-sequences.

The foregoing, and other features and advantages of the invention, will be apparent from the following, more particular description of the preferred embodiments of the invention, the accompanying drawings, and the claims.

5   BRIEF DESCRIPTION OF THE DRAWINGS

For a more complete understanding of the invention, the objects and advantages thereof, reference is now made to the following descriptions taken in connection with the accompanying drawings in which:

Fig. 1 illustrates a conventional direct sequence spread spectrum spreading
10   technique;

Figs. 2A-2D illustrate frequency spectra in a conventional direct sequence spread spectrum communication system;

Fig. 3 illustrates a parallel spread spectrum communication system according to an embodiment of the invention;

15   **Fig. 4** illustrates a process for transmitting a parallel spread spectrum signal according to an embodiment of the invention;

Fig. 5 illustrates a process for receiving a parallel spread spectrum signal according to an embodiment of the invention;

Fig. 6 illustrates a signal diagram of parallel spreading of data according to an
20   embodiment of the invention;

Fig. 7 illustrates a single channel parallel spread spectrum transmitter system according to an embodiment of the invention;

Fig. 8 illustrates a hardware component diagram of a QPSK differential encoder according to an embodiment of the invention;

25   **Fig. 9** illustrates a parallel spread spectrum receiver system according to an embodiment of the invention;

Fig. 10 illustrates a Walsh code correlation and decoding circuit according to an embodiment of the invention;

Fig. 11 illustrates a hardware component diagram of a differential PSK
30   demodulator according to an embodiment of the invention; and

Fig. 12 illustrates a dual channel parallel spreading system according to an embodiment of the invention.

DETAILED DESCRIPTION OF PREFERRED EMBODIMENTS

5   The preferred embodiments of the invention are now described with reference to **Figs. 3-12**, wherein like reference numbers indicate like elements and the left most digit(s) of each reference number corresponds to the figure in which the reference number is first used.

These preferred embodiments are discussed in the context of wireless telephone communication systems. However, the invention can be practiced in a wide range of 10 applications, for example, broadband wireless point-to-point and point-to-multipoint digital communications links; low power wireless applications; telemetry applications using CDMA; WLAN applications; and secure communication channels. The preferred embodiments involve parallel bi-sequential spread spectrum ("PBSS") techniques of spreading coded data over a predetermined sequence in accordance with the invention. Thereby, the invention 15 simultaneously provides the benefit of additional processing gain, data forward error correction ("FEC"), and other benefits and advantages.

The invention can be applied to any existing digital communications channel to essentially create a pseudo direct sequence spread spectrum communications link utilizing byte by byte [B X B] or multiple byte [MB X MB] parallel spreading of an input digital data. When 20 combined with a DSSS communications channel, a dual layered parallel spreading of the data stream occurs. The invention widens the bandwidth requirements and increases the processing gain for the link.

Referring to **Fig. 3**, a spread spectrum communication system 300 is depicted according to an embodiment of the invention. System 300 comprises transmitting station 310 25 and receiving station 320. Transmitting station 310 communicates a parallel spread spectrum signal 330 to receiving station 320. To facilitate bilateral communications, receiving station 320 acting as a transmitter would transmit a parallel spread spectrum signal 340 to transmitting station 310 acting as a receiver. One of ordinary skill in the art will recognize that parallel spread spectrum signals 330 and 340 can be transmitted via a wireless network (not shown), such as a 30 cellular phone service network or personal communications services ("PCS") network. For example, transmitting station 310 and receiving station 320 can be in the same cell or different

cells of a cellular network or in cells of two different networks. The cellular network can comprise one or more base stations, which each operate in a respective cell, and a central office referred to as a mobile telephone switching office ("MTSO"). Each base station can comprise one or more transmitters and/or receivers that relay parallel spread spectrum signals 330 and 340

5   to enable a cellular network to communicate with transmitting station 310 and/or receiving station 320. In such embodiments, the MTSO handles all phone connections to land-based phone systems and other cellular networks, and controls all of the base stations in a particular region. Parallel spread spectrum signals 330 and 340 can be converted at a base station or the MTSO into a differently formatted signal depending on the format required by a land-based

10   communication system or other cellular network as necessary.

In this preferred embodiment, parallel spread spectrum signal 330 is generated according to process 400 depicted in **Fig. 4**. In an embodiment of the invention, transmitting station 310 encodes (step 410) a digital data signal with a primary coding scheme. The primary encoding scheme employs orthogonal codes, such as orthogonal Walsh functions, of length 2^n.

15   For example, the primary codes may be four (4), eight (8), or sixteen (16) bit Walsh codes. Secondary encoding is performed (step 420) with a secondary code to spread the primary encoded data. The secondary code can be any type of an even ordered code, for example, M sequence, Barker, Gold, Kasami, and the like, but preferably, a PN-sequence. The secondary code is synchronously multiplied across the complete primary sequences with the requirement

20   that the secondary sequence must be an integer multiple of the length of the primary sequences. For example, if the primary codes are eight (8) bit Walsh codes, the secondary code must be a integer multiple of eight (8), for example, sixteen (16), twenty-four (24), thirty-two (32), forty-eight (48), or sixty-four (64), etc., bit PN-sequence. Upon completion of secondary encoding, the signal is modulated (step 430) and then transmitted (step 440) to receiving station 320.

25   **Fig. 5** illustrates a process 500 for receiving parallel spread spectrum signal 330 according to this preferred embodiment of the invention. Parallel spread spectrum signal 330 is first received (step 510) at receiving station 320. The parallel spread spectrum signal 330 is digitized (step 520) and then despread (step 530) using a stored secondary sequence corresponding to the secondary sequence used by transmitting station 310. Upon completion of

30   despreading, the signal is demodulated (step 540) and then decoded (step 550) using the scheme employed in transmitting station 310.

With this embodiment, a potential processing gain of 18.4 dB (as the following details will illustrate) can be achieved if an eight (8) bit Walsh code is used as the primary sequence and a forty-eight (48) PN-sequence is used as the secondary sequence. Higher levels of processing gain can be achieved by using longer length primary and/or secondary codes.

5 However, the level of complexity in receiving station 320 electronics is directly proportional to the length of the codes, and hence may limit the practical application of larger codes. Comparatively, to achieve a processing gain of 18.4 dB in a conventional DSSS system, a spreading code of greater than sixty-nine (69) bits would be necessary, which is impracticable for high data rate applications using current technology.

10 **Fig. 6** illustrates a signal diagram 600 of parallel spreaded data according to an embodiment of the invention. As shown, an eight (8) bit orthogonal code 610 is spread by a forty-eight (48) bit parallel PN-sequence 620 resulting in a parallel spread spectrum data signal 630. As previously stated, the parallel sequence must be an integer multiple of the chosen length of the orthogonal code. Each data symbol 640 is spread by six (6) bits 650 of a parallel spreading

15 sequence resulting in a potential processing gain of 7.78 dB (10 log 6). Once the appropriate orthogonal and parallel PN-sequence are chosen they are fixed for the duration of a communications session. CDMA communications can be achieved when each receiver is allocated different orthogonal PN-sequences with or without varied lengths.

In essence, a large parallel spreading sequence is used over multiple data bytes.

20 The spreading sequences utilized can be, for example, M sequence, Barker, Gold, Kasami, or any type of PN-sequence. The parallel spreading in accordance with the invention can utilize differential encoding of the data stream in the transmit path to simplify data recovery in the receiver. If the parallel spreading scheme is applied to a M-ary modulation link then both in-phase (I) and quadruture (Q) channels can be spread using different PN-sequences to enhance

25 channel security.

M-ary modulation systems send more information per transmitted signal transition (symbol) than binary systems. Since $\log_2(M)$ bits are required to select one of M possibilities, each waveform conveys $\log_2(M)$ bits of information. Each transmitted waveform represents a $\log_2(M)$-bit symbol. Examples of M-ary schemes are illustrated in Table 1.

Table 1: M-ary schemes.

M-ary	Modulation Scheme
4	QPSK
8	8 PSK
16	16 QAM
64	64 QAM

In an embodiment of the invention, Walsh encoding of the primary data provides initial spreading and coding gain. An eight (8) bit Walsh encoder will provide a potential processing gain of 9 dB and coding gain of 1.6 dB. The link uses an advanced protocol and data is conveyed in packet format. A preamble signifies the start of transmission to initialize acquisition at the receiver. Differential binary phase-shift keyed ("DBPSK") modulation is initially utilized for the preamble and DQPSK for subsequent data packet transmission. Differential refers to the fact that the data is transmitted in the form of discrete phase shifts $\Delta\theta$, where the phase reference is the previously transmitted signal phase. This method reduces the complexity of the demodulation process as an absolute phase reference is not required.

Fig. 7 illustrates a parallel spread spectrum system 700 with a single channel according to an embodiment of the invention. Incoming data 772 is scrambled by a scrambler 710 to spectrally whiten and remove any DC offset from the data. In this embodiment of the invention, orthogonal Walsh functions are used to encode and spread the data stream with a Walsh encoder 720. The resulting data is segmented into four (4) bit nibbles with three (3) bits defining magnitude and the remaining bit designating sign. The magnitude bits identify one of eight (8) Walsh codes and the sign bit defines whether a true or inverted Walsh code is selected. This introduces system processing gain in the form of both the spread and the coding. The spreading gain is 9 dB (10 log 8) while the use of highly orthogonal Walsh functions provides a coding gain of 1.6 dB. Thus, the use of Walsh codes provides an effective system gain of 10.6 dB. However, alternative digital modulation schemes involving in-phase (I) and a quadrature (Q) channels can be used with the invention. Accordingly, in an alternative embodiment, each channel utilizes a different parallel spreading sequence to greatly enhance channel security.

M-ary bi-orthogonal keying ("MBOK") modulation is a technique whereby the data is block encoded using orthogonal codes and can be implemented in binary ("BMBOK") or

Quadrature ("QMBOK") format. This technique generates a coding gain which improves the link bit error rate ("BER") performance through implementation of FEC algorithms at the receiver. Therefore, MBOK modulation is more efficient than BPSK, for example, E_b/N_o is 8 dB as opposed to 9.6 dB at $1e10^{-5}$ BER.

5   It should be noted that Walsh encoding can be implemented as part of the preferred embodiment with the above-identified benefits and advantages, but in alternative embodiments it can be circumvented with additional processing gain being obtained directly from parallel spreading. Walsh encoding is preferred because of the orthogonality of the codes and the FEC attributes that can be achieved. Walsh codes exhibit zero cross-correlation only 10 when there is zero phase offset or perfect synchronism. When offset, Walsh codes exhibit much larger cross-correlation values and much worse auto-correlation than PN-sequences. Hence, the overlaid parallel PN spreading sequences are used to extract the phase and timing information necessary to coherently decode the Walsh sequences at the receiver. Unencoded preambles are initially transmitted in order to achieve initial acquisition at the receiver. A preamble generator 15 740 generates the preamble then signals via signal 774 the medium access controller ("MAC") (not shown) to send the packetized data for Walsh encoding. The MAC controls the flow of data between the host system and the radio section.

Differential encoding of the data stream occurs to simplify the phase determination requirement in the demodulation process. A differential encoder 730 utilizes the 20 previous symbol as a phase reference for determining the current symbol decision. This negates the prerequisite for the transmission of a constant phase reference in a coherent detection system. Differential encoding for BPSK modulation is achieved by simply XORing the present and previous symbol values. However, differential encoding for QPSK is more complex as there are sixteen possible states as shown in Table 2.

25   **Fig. 8** illustrates a QPSK differential encoder circuit 800 according to an embodiment of the invention. Hardware comprises quadruple two-input exclusive-or gates 810 and 820 connected to two-bit adder 830. The operation of circuit 800 would be apparent to one of ordinary skill in the art.

Table 2: Differential Encoder Sequence QPSK

New Input IN(I,Q)$_K$	Previously Encoded OUT (I,Q)$_{K-1}$			
	0 0	0 1	1 1	1 0
0 0	0 0	0 1	1 1	1 0
0 1	0 1	1 1	1 0	0 0
1 1	1 1	1 0	0 0	0 1
1 0	1 0	0 0	0 1	1 1

Referring to **Fig. 7** again, a data buffer 750 holds the data byte(s) prior to parallel spreading and ensures that the data and PN-sequence can be synchronized. For example, Walsh encoder 720 provides synchronization pulses to a synchronizer 732. To ensure that the Walsh codes and PN-sequences are aligned in time, synchronizer 732 provides timing information to data buffer 750, a PN-sequence generator 760 and a parallel spreader 770. PN generator 760 is programmed to generate short through to very long PN-sequences. The PN-sequence spreads the data in parallel via parallel spreader 770 with multiple PN bits per data symbol. Output data stream 776 is modulated using a digital modulation scheme such as BPSK or QPSK.

Fig. 9 and **Fig. 10** illustrate the major components of a parallel spread spectrum system (receiver) 900 according to an embodiment of the invention. **Fig. 9** illustrates both I 902 and Q 904 channels in which DPSK is the modulation scheme. **Fig. 10** illustrates the Walsh code correlation and decoding circuit 1000 along with FEC; to enhance clarity, the In-phase [I] channel is illustrated only, however other channels may be used. The operation of circuit 1000 would be apparent to one of ordinary skill in the art.

Referring to **Fig. 9**, receiver 900 despreads the parallel spread sequence according to an embodiment of the invention. Specifically, an IF signal is down-converted to base-band where it is digitized by a dual four (4) bit analog to digital converter ("ADC") 910. A sampling rate of four times the maximum chip rate is utilized. A carrier tracking digital phase locked loop ("DPLL") is provided by a carrier phase detector 930, a lead/lag filter 940, a numerically controlled oscillator ("NCO") 950, and a complex multiplier 920. A NCO is an oscillator which generates digital sample values corresponding to sinusoidal or other waveforms. The purpose of the DPLL is to remove any carrier offset that would be attributed to tolerances in the RF down-

conversion process. A quadrature NCO multiplies the received samples to remove this carrier offset prior to correlation. A secondary DPLL error signal is derived from the demodulation section. This phase aligns or synchronizes the samples introduced to a PN matched filter correlator 960 to optimize receiver performance.

5   PN matched filter 960 comprises a uniquely programmable multi-stage serial sliding correlator.   In operation, PN matched filter 960 computes the cross correlation between the input and the programmed PN maximal sequence. The correlation peak is utilized to initialize a parallel accumulate, integrate, and dump sequence which, in turn, extracts both the multi-byte samples and byte timing information. The product from each of the bit accumulators in PN

10   matched filter 960 are fed in parallel to a correlation and symbol tracking processor 970 where correlation of each bit is confirmed and the symbol timing information is extracted from the extracted data samples. Correlation is achieved by computing the magnitude of the sums of the I and Q channel correlation sums approximated by the equation, Max [ABS(I)*ABS(Q)] + ½ Min[ABS(I)*ABS(Q)]. The computed value is used to generate the multi-byte tracking reference

15   clock signal.

Programmable thresholds and intelligent tracking are implemented to ignore false detects and automatically insert missing correlation pulses. This multi-byte detection pulse initializes the parallel correlation which extracts the symbol timing by computing the magnitude of the symbol correlation power which in turn forms a reference for the symbol tracking process.

20   The extracted despread symbol samples along with correlated timing information from the symbol tracking processor are then forwarded to a DPSK demodulator 980.

DPSK demodulation is carried on each symbol by computing the "dot" and "cross" products for each using the despread information from the current and previous parallel correlation process. For BPSK modulation the "dot" product alone allows determination of the

25   phase shift between successive samples. For QPSK modulation both the "dot" and "cross" products are necessary to determine the phase shift. Mathematically, the dot and cross products are given by;

$$dot(k) = I_K \cdot I_{K-1} + Q_K \cdot Q_{K-1} \quad and,$$
$$cross(k) = Q_K \cdot I_{K-1} - I_K \cdot Q_{K-1},$$

where I and Q are the In-phase and Quadrature samples for the current, K, and previous, K-1, symbols. Examination of these products in the complex plane reveals that this method will correctly demodulate differentially encoded QPSK signals in the format illustrated in Table 2.

A hardware implementation of a differential PSK demodulator 1100 according to an embodiment of the invention is illustrated in **Fig. 11**. The operation of demodulator 1100 would be apparent to one of ordinary skill in the art.

The dot and cross products can also be utilized to generate an additional error signal for the initial DPLL function. This automatic frequency control ("AFC") error signal reflects the sine of the phase difference between the present and prior symbol after correcting for the estimated phase increment between symbols due to the PSK modulation. Mathematical analysis yields a close approximation which can be applied using dot and cross products. The equations are:

$$AFC\_Error_{BPSK} = Cross \cdot Sign[Dot] \qquad and,$$

$$AFC\_Error_{QPSK} = (Cross \cdot Sign[Dot]) - (Dot \cdot Sign[Cross]),$$

respectively, for BPSK and QPSK modulation schemes. The error signals from each of the parallel processing channels are combined and averaged before being fed through the loop filter to the NCO. This function essentially removes minor frequency errors and hence ensures optimal receiver performance.

The recovered I and Q data is latched into parallel to serial converters. In another embodiment of the invention, additional signal processing may be required to accommodate interfaces with existing Walsh decoders. The data samples are output in parallel I 1202 and Q 1204 busses to a Walsh code FEC 1210 of a dual channel parallel spread spectrum system 1200 as illustrated in **Fig. 12**.

The Walsh correlation, demodulation, and FEC processes depend on the parallel despreading sections to correctly remove carrier frequency and phase offsets. The symbol timing processor from the parallel despreading section also provides the phase reference needed to coherently correlate and decode the Walsh code sequences.

FEC processor 1210 examines the I 1202 and Q 1204 data bus and compares the received bytes with one of sixteen (16) possible byte patterns. Intelligent processing is used to correct bit errors within the received I and Q symbols. FEC 1210 operates in conjunction with

14

Walsh decoder 1220 to ensure optimal performance. The orthogonality property of Walsh codes enhances their FEC attributes and hence minimizes BER across a link.

The output from the FEC process is applied to a bank of sixteen (16) correlators (not all shown), eight for each I and Q channel, which multiply the input by the corresponding Walsh code, accumulate, integrate, and dump over the byte period. A "Biggest picker" 1230 for the I channel and a "biggest picker" 1235 for the Q channel analyze the correlation peaks from the respective eight correlators and output the corresponding data for the determined Walsh code to a sign correction and data serialization 1240. The Walsh decode information is routed back to FEC processor 1210 to confirm the Walsh decoder and FEC processes. Irregularities between processes will result in secondary reprocessing of the input sample. Failure of this process will result in generation of an error signal, which can be utilized with the link protocol to initialize a re-transmit algorithm. Once the Walsh codes are successfully decoded, the I and Q data is determined and combined into a signal data stream.

The data stream is descrambled using polynomial division and cycle redundancy checking ("CRC") is performed on the data packet by a data descrambler and CRC detect 1250. The data is then serially output to a MAC to complete the receiver operation.

The most critical processing area relates to the parallel processing requirements in the receiver. A typical processing cycle from PN acquisition through to data recovery should be implemented in 0.4 x Q, where Q equals the acquisition time. For a E1 data stream utilizing the forty-eight (48) bit parallel spreading example illustrated, complete receiver processing is required within 1.5 μs.

The present invention is a novel parallel spread spectrum system and method that combines the orthogonal properties of Walsh codes with the close correlation characteristics of PN-sequences to produce a robust communications technique that can be implemented in point to point or point to multi-point communications links. Independent parallel spreading sequences can be allocated within a network to implement CDMA. In an embodiment of the invention, parallel spreading is dynamic in that the Walsh encoder is programmable and the parallel spreading code length can be varied. A user can determine maximal processing gain for a fixed data rate within an allocated bandwidth.

The example illustrated in the foregoing description and figures utilizes an eight (8) bit Walsh encoder and a forty-eight (48) bit PN-sequence to achieve a system processing gain

of 18.4 dB (9 + 1.6 + 7.8), which potentially increases the effective range of a PSS link over a conventional link by an eight fold figure. Alternative embodiments of the invention can have different size Walsh encoders and PN-sequences. It is preferable to use smaller length codes in order to maximize acquisition speed and minimize design complexity.

5   In another embodiment of the invention, further layered spreading sequences can be implemented to enhance the processing gain and CDMA characteristics. For example, in addition to a secondary spreading sequence, a third sequence may be used in parallel with the primary coding and secondary sequence.

          In another embodiment of the invention, coherent demodulation is used to negate

10   the need for differential encoding. In alternative embodiments, a QAM based or coded orthogonal frequency division multiplex technology is used as the modulation scheme.

          Although the invention has been particularly shown and described with reference to several preferred embodiments thereof, it will be understood by those skilled in the art that various changes in form and details may be made therein without departing from the spirit and

15   scope of the invention as defined in the appended claims.